What is the impact on farmer nitrogen fertilizer use of incorporating the effects of nitrous oxide emissions?

Robert J. Farquharson[A], Deli Chen[B] and Yong Li[C, D]

[A]Melbourne School of Land & Environment, The University of Melbourne and Future Farm Industries Cooperative Research Centre, Parkville, VIC, Australia, email bob.farquharson@unimelb.edu.au
[B]Melbourne School of Land & Environment, The University of Melbourne and Future Farm Industries Cooperative Research Centre, , Parkville, VIC, Australia, email deli.chen@unimelb.edu.au
[C]Melbourne School of Land & Environment, The University of Melbourne, Parkville, VIC, Australia, email yong.li@unimelb.edu.au
[D]Institute of Subtropical Agriculture, The Chinese Academy of Sciences, Hunan 410125, China, email yli@isa.ca.cn

Abstract
The use of nitrogen (N) fertilizer continues to be important for crop production, but the increased recent focus on nitrous oxide (N_2O) as a potent greenhouse gas has added new considerations to fertilizer decisions. We present an economic decision framework which includes agricultural and environmental dimensions and provides policy information for the proposed Carbon Pollution Reduction Scheme (CPRS) in Australia. The economic framework indicates the 'best' fertilizer decision from both agricultural and environmental viewpoints. The former focuses on profit, based on likely crop responses to added fertilizer and prices, and marginal revenues and marginal costs. Marginal revenue is the willingness to pay for fertilizer by the crop producer, or the input demand. The price elasticity of demand for fertilizer is relatively unresponsive, meaning that an increase in fertilizer price will have a proportionally-lower decrease in amount demanded. In this study we also examine wheat grower N fertilizer decisions by incorporating the effects of greenhouse gas (N_2O) emissions, based on a carbon price of \$25/t of carbon (C) dioxide equivalent (CO_2e). Because of the inelastic demand and the relatively low N_2O emissions for Australian wheat cropping the reduction in farm-level demand for fertilizer is relatively small. We illustrate our findings with a case study of wheat production in Western Australia.

Key Words
Fertilizer decisions, economics, agriculture, greenhouse gas, nitrous oxide.

Introduction
We present an economic decision framework for N fertilizer applied to crops. Recent price fluctuations have emphasised the importance of economic considerations in making these fertilizer decisions. Also important is the emerging focus on the agriculture-induced greenhouse N_2O emitted to the earth's atmosphere and proposals to mitigate emissions and initiate emissions trading (Australian Government 2008). What is the impact of imposing a price for C on fertilizer in terms of likely farm-level responses?

These questions can be investigated by presenting an appropriate fertilizer decision framework. Standard micro-economic theory for the firm based on a production function, relative prices and the premise that profits are important to farmers leads to the marginal economic framework which can be applied to fertilizer decision making. We use a case study of wheat production in the central wheat belt of Western Australia as an illustration. This marginal economic framework is not new, it has been outlined by Heady (1952) and many others. But it has not been widely used in applied agricultural decision making.

The Australian Government (2008) has proposed the introduction of a CPRS, but carriage of this legislation is politically uncertain. In the meantime a number of issues for agriculture and the CPRS can to be investigated, including how such a scheme would operate in an industry with many small producers whose emissions are difficult to measure and monitor. Considerations of effectiveness, compliance costs, administration costs and avoidance of distortions among producers are important.

An issue that does not seem to have been flagged is the likely response by farmers in their crop management decisions if the price of C is reflected in prices paid by farmers for inputs and prices received for outputs. We investigate the former issue for wheat production and N fertilizer in Australia. By how much is N fertilizer usage likely to fall if the price of fertilizer rises?

Economic framework
The conventional production economics framework addresses the question of 'how much' of an input to be used to maximize crop profits. It has been developed based on a hypothesized production response to added inputs, a set of (fixed) prices for inputs and outputs, and an assumption that farmers want to make a profit from these decisions. The mathematical solution procedure solves for the necessary and sufficient conditions of the constrained optimization problem when the production function is substituted into the profit function (e.g. see Silberberg 1990). Applications in a farm production economics framework were presented by Heady (1952). The condition necessary for the profit-maximizing level of input is that the input should continue to be added until the declining marginal revenue just equals the marginal cost, provided that the sufficient condition, of production concavity, holds. The production function is assumed to be continuous, smooth, (twice) differentiable and concave. According to Thornley and France (2007), many biophysical responses exhibit diminishing returns which characterize concavity. The general mathematical approach presented by Silberberg (1990) has been set out for the crop/fertilizer decision by Farquharson (2006). However, the mathematical solution approach which relies on differentiability is not necessary for the single-input/single-output problem (CIMMYT 1988), and a more intuitive approach is presented here. This involves predicting agricultural and environmental production responses to added N fertilizer and investigating how the environmental effects influence the optimal agricultural decisions.

Methods
The response of wheat yield to increased levels of soil available N was predicted using the Water and Nitrogen Management Model (WNMM) (Li *et al*. 2007; Li *et al*. 2008). WNMM was calibrated and validated for a wheat-cropped soil at Cunderdin in the central wheat belt of Western Australia (Barton *et al.* 2008). Thirty-seven years of climate data (1970 to 2006) were used for the analysis. Using these inputs WNMM was run with a base level of 30 kg units of soil mineral N plus additional 25 kg units from zero to 150. Predictions of wheat yield (cv. Carnamah) were developed and mean yield responses were used as a basis for the economic analysis.

N_2O emissions were estimated using two calculations of the global warming potential (in units of CO_2e) of alternative fertilizer decisions. The calculations were based on WNMM results and an IPCC default value (IPCC 2009):
CO_2e = annual N_2O emissions (kg N/ha from WNMM) * ratio of molecular weights (N_2O/N) * 310 (1)
CO_2e = N applied (kg/ha) * 0.01 (IPCC default value of 1%) * ratio of molecular weights * 310. (2)

The fertilizer price used was $1.24/kg of N contained in urea, based on a price of $570/t bulk fertilizer in Australia (Incitec/Pivot Company personal communication, September 2009). Wheat price information was obtained from Australian Wheat Board (AWB) Western Pool No. 1 for 2009-10 (AWB Limited, 2009). A (port delivered) price of $248/t FOB and GST exclusive was translated into a farm-gate price of $218/t by deducting typical freight, levy and receival costs. The Carnamah variety is AUH2 grade wheat which does not receive premiums for protein increments.

The economic analysis was conducted by assuming that the different levels of soil N represent different N fertilizer decisions for a single crop year. Starting from the lowest level of fertilizer, the change in yield is multiplied by the wheat price to develop the marginal revenue for each additional kg of soil nitrate N. The marginal cost for each additional kg of N is the N purchase price. The comparison of marginal revenue and cost starts from an initially-low level of soil N fertility and evaluates decisions to sequentially apply extra amounts of N. In the analysis this marginal approach is applied to both the agricultural and environmental responses to added soil N.

The marginal revenue schedule represents the willingness to pay for fertilizer by the wheat grower based on an expected production response, or the demand for the input by the wheat grower. As for any demand function the elasticity can be calculated to provide additional policy information. The price elasticity of demand is the expected change in fertilizer quantity used for a small percentage change in the fertilizer price.

Results
The yield response for different levels of soil N is shown in Figure 1. The mean yield shows the concave characteristic of increasing at a decreasing rate up to a maximum. The marginal revenue and marginal agricultural cost for the mean yield response using the above prices are shown in Figure 2. The purchase

price of urea fertilizer was $1.24/kg N (marginal cost), and crop harvest was assumed to be by contractor and charged at a constant rate per ha. The best soil N level agriculturally (N^{*a}) to satisfy the profit objective is around 80 kg N per ha (Figure 2). Arc elasticities were calculated for increasing prices along the input demand (marginal revenue) schedule. The elasticities varied from -0.1 to -0.3, a relatively inelastic response.

The estimated N_2O emissions (from equations (1) and (2)) are shown in Table 1 and plotted in Figure 1. There is a substantial difference in predicted emissions from these two approaches. Perhaps the level of N_2O emissions from Australian wheat is much less than the predictions using the IPCC default value? The N_2O emissions in Table 1 were converted to units of t CO_2e and expressed per unit of soil available N, so that the environmental costs could be directly compared to the agricultural costs.

The marginal costs of N_2O were calculated based on a price of $25/t CO_2e. These marginal costs are $0.12/kg N/ha using the IPCC estimates, but only $0.01-0.02/kg N/ha using the WNMM predictions. The combined marginal agricultural and environmental costs of applying nitrogen fertilizer for agricultural purposes using the IPCC calculation are shown in Figure 2. The marginal cost using WNMM results is very close to the agricultural cost, and has not been plotted separately.

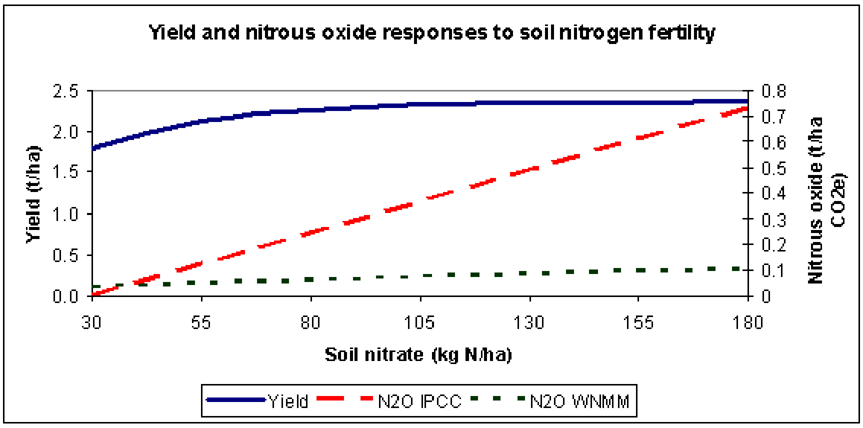

Figure 1. Wheat yield and nitrous oxide responses to increased nitrogen fertilization predicted at Cunderdin, Western Australia.

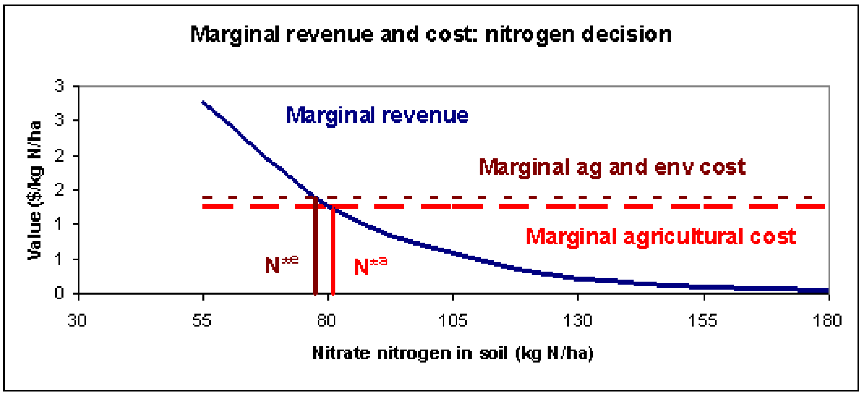

Figure 2. Marginal revenues and costs for the agricultural and environmental decision.

Table 1. Predicted CO_2e of N_2O emissions from N fertilizer applied to wheat in Western Australia.

N_2O emissions (kg/ha CO_2e)	Level of N fertilizer (kg N/ha) applied to base of 30 kg/ha in soil						
	0	25	50	75	100	125	150
WNMM (1)	31	46	58	72	83	93	100
IPCC formula (2)	0	122	244	365	487	609	731

When the IPCC-based environmental cost of N fertilizer is included the best fertilizer decision (N^{*e}) is reduced by about 4 kg N per ha (i.e. by about 5%) from the agricultural decision (N^{*a}). Marginal costs based on the WNMM results do not change the agricultural decision.

Discussion

The N fertilizer decision for wheat growers involves economic considerations, not least because of the costs and benefits involved and the alternative uses for scarce and costly funds. There have been substantial price fluctuations for N fertilizer in recent years. The traditional marginal economic framework shows the 'best' level of fertilizer for profit purposes. As well, the input demand function gives other information for policymakers. The inelasticity of demand for fertilizer means that a policy objective of substantially reducing agricultural N_2O emissions by increasing the N price is unlikely to have a large effect on farm-level usage of fertilizer. An increase in price will reduce the quantity used but not by very much, because soil fertility is such a necessary part of the crop production process. But we can say more than this if we predict the N_2O emissions associated with each N fertilizer decision. Using a C price of $25/t CO_2e we calculated the marginal costs associated with N_2O emissions using two different methods. Using the IPCC default value, the N_2O costs rise as more fertilizer is applied. However, the indicated impact on optimum fertilizer use is small, a reduction of around 5% for the average response. Using the WNMM results there appear to be much lower levels of N_2O emissions and the cost implications are trivial.

Conclusion

The economic decision framework presented here can provide important information for decision makers at both the farm and policy level. By using a crop simulator we have shown the likely size of farm-level response if an emissions trading scheme is introduced resulting in an increased price for N fertilizer. Imposing a price on C may have less of an impact on agricultural fertilizer usage than perhaps otherwise thought. This result adds to other calls (e.g. Matson *et al.* 1998) to develop improved N fertilizer formulations that emit less N_2O into the atmosphere.

References

Australian Government (2008) *Carbon Pollution Reduction Scheme: Australia's Low Pollution Future, White Paper*. Online at www.climatechange.gov.au/whitepaper/summary, accessed 23 September 2009.

AWB Limited (2009) *0910 Western Pool Increments*. Online at http://www.awb.com.au/growers/awbpoools/awbpools/, accessed 29 October 2009.

Barton L, Kiese R, Gatter D, Butterbach-Bahl K, Buck R, Hinz C and Murphy DV (2008) Nitrous oxide emissions from a cropped soil in a semi-arid climate. *Global Climate Change Biology* **14,** 177-192.

CIMMYT (1988) *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*. Completely revised edition. Mexico, D.F.

Farquharson RJ (2006) Production response and input demand in decision making: nitrogen fertiliser and wheat growers. *Australian Agribusiness Review*, Volume 14(5) http://www.agrifood.info/review/.

Heady EO (1952) *Economics of Agricultural Production and Resource Use* (Prentice-Hall, Englewood Cliffs, New Jersey).

IPCC (2009) *The IPCC Assessment Reports*, online at http://www.ipcc.ch/, accessed 30 October 2009.

Li Y, Chen D, Barker-Reid F, Eckard R (2008) Simulation of N_2O emissions from rain-fed wheat and the impact of climate variation in southeastern Australia. *Plant and Soil* **309**, 239-251.

Li Y, Chen DL, White RE, Zhang JB, Li BG, Zhang YM, Huang YF, Edis R (2007) A spatially referenced Water and Nitrogen Management Model (WNMM) for (irrigated) intensive cropping systems in the North China Plain. *Ecological Modelling* **203,** 395-423.

Matson PA, Naylor RL, Ortiz-Monasterio I (1998) Integration of Environmental, Agronomic, and Economic Aspects of Fertilizer Management. *Science* **280**, 112-115.

Silberberg E (1990) The Structure of Economics, A Mathematical Approach. (Englewood Cliffs; New Jersey).

Thornley JHM, France J (2007) *Mathematical Models in Agriculture: Quantitative Methods for the Plant, Animal and Ecological Sciences*. 2nd edition, (CAB International; Wallingford, UK).